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Retraction

Retracted: Antioxidant Activity and Characterization of One New Polysaccharide Obtained from *Perigord Truffle* (*Tuber huidongense*)

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Evidence-Based Complementary and Alternative Medicine has retracted the article titled "Antioxidant Activity and Characterization of One New Polysaccharide Obtained from *Perigord Truffle* (*Tuber huidongense*)" [1] at the request of the authors. The first author says the HPLC and NMR results are not reproducible, while the fourth author did not approve the article's submission and disputes the authorship.

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[1] Y.-F. Chen, W.-W. Jiang, S.-Q. Zhang, J.-Q. Kan, and Y. Liang, "Antioxidant Activity and Characterization of One New Polysaccharide Obtained from *Perigord Truffle* (*Tuber huidongense*)," *Evidence-Based Complementary and Alternative Medicine*, vol. 2016, Article ID 3537193, 7 pages, 2016.

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Research Article

Antioxidant Activity and Characterization of One New Polysaccharide Obtained from *Perigord Truffle* (*Tuber huidongense*)

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As a medicinal and edible fungus parasitizing on the trees, Perigord Truffle (*Tuber huidongense*) is well known for its delicious taste, unique smell, and high medical value for healthcare. One new water-soluble nonstarch polysaccharide (PST-W with the yield of 0.41%) from *Perigord Truffle* (*Tuber huidongense*) was purified and identified on structural characteristics for the first time. The characterizations of PST-W were studied on physicochemical properties, main components of monosaccharide(s), and molecular structure. The monosaccharide compositions of PST-W were studied and identified as glucan, only containing D-glucoses with the molecular structure of $[\rightarrow 6)\ \alpha\text{-D-Glcp}\ (1 \rightarrow 6)\ \alpha\text{-D-Glcp}\ (1\rightarrow]_n$ by methylation analysis and NMR. In the determination of total reducing capacity, the reducing abilities of polysaccharide extracts could be listed as vitamin C > PST-W > crude polysaccharides-3 > crude polysaccharides-2 > crude polysaccharides-1. All of PST-W, crude polysaccharides-2, and crude polysaccharides-3 were relatively good scavenger for 1,1-Diphenyl-2-picrylhydrazyl radical 2,2-Diphenyl-1-(2,4,6-trinitrophenyl)hydrazyl radicals with IC_{50} of 2.81, 4.17, and 3.44 mg/mL, respectively. However, $O_2^{-\bullet}$ clearing abilities of PST-W and crude polysaccharides were obviously weaker. The activities of total crude extract were the worst, indicating that the impurities might negatively affect the antioxidant activity. Thus, the separation and purification of polysaccharides were significant to increase the antioxidant activity in some degree.

1. Introduction

There is a long history on the study of tuber, since botanist Michael recorded this species in 1792 for the first time and fungi scientist Fillet confirmed its position in the taxonomy of fungi in 1823. The polysaccharide of *Tuber sinense* (PST) is a protein-bound polysaccharide first extracted from the Chinese truffle, and it has been utilized widely for the treatment of tumors. The scientific team of Hu et al. explored the effect of PST on tumor and immune system [1]. It was reported that PST dramatically inhibits the growth of S180 sarcoma and Ehrlich's ascites carcinoma sarcoma in vivo, but there was no related effect on cell proliferation in vitro, which meant that the antitumor effect of PST might be related to immunomodulation but not cytotoxic activity. In another side, PST therapy increased the weight of mouse spleen and the level of serum antibodies, which proved the assumption as well. As a fungous polysaccharide with low toxicity and good water solubility, PST showed significant antitumor potential and might have much more medicinal value. The research group of Tang et al. not only aimed to increase the production of extracellular polysaccharides in the plantation area of medicinal mushroom Chinese truffle *Tuber sinense* [2] but also separated more than fifty-two polysaccharides from the fermentation systems of *Tuber melanosporum*, *Tuber indicum*, *Tuber sinense*, and *Tuber aestivum* and the fruiting bodies of *Tuber indicum*, *Tuber himalayense*, and Tuber sinense by elution with an activated carbon column. The

polysaccharides from *Tuber* fermentation system exhibited relatively higher in vitro antitumor activity against HepG2, A549, HCT-116, SK-BR-3, and HL-60 cells than those from *Tuber* fruiting bodies [3]. Besides, the specific aromas and polysaccharides of *Perigord Truffle* had been exploited on plenty of special pharmacological effects, such as sexual performance improving, antitumor effects, and antiaging effects [2, 4, 5].

As a medicinal and edible fungus parasitizing on the trees, the wild *Perigord Truffle* (*Tuber huidongense*, Huidong city of Sichuan province in China) was obtained as experimental subject by our research team for several years. Sixty-five main compounds of truffle aroma were identified, including most components of alcohols and lipids by GS-MS [6]. According to the previous study on the new water-soluble nonstarch polysaccharide (PST-W) from *Perigord Truffle* (*Tuber huidongense*), it indicated that the molecular weight of PST-W was 7.29×10^5 Da approximately [7]. Studying physicochemical properties and compositions of PST-W would do help to understand its potential antioxidant activity and other pharmacological activities, which will also provide reference and basis for the main pharmacological activity of truffle and its corresponding mechanisms. Therefore, the systematic study on its components of aromas and polysaccharides will be meaningful for its potential utilization with broad market prospect.

2. Methods

2.1. The Source of the Truffles. The source of *Tuber huidongense* is from Huidong city of Sichuan province in China. All sources, identified by Dr. Jian-quan Kan, were frozen and vacuum-packed.

2.2. Polysaccharide Purification and Purity Identification. Main processes were described in Figure 1. The yields of samples in each part were calculated after freeze drying. The purity of PST-W was detected by Shimadzu HPLC with RID-10AT detector (differential detection). Pump was IC-10AT with a Cosmosil amino column (4.6×250 mm). The injection volume was 20 μL at 25°C with flow rate of 0.4 mL/min, and the wavelength of detection was at 197 nm with the mobile phase of ultrapure water.

2.3. Structural Characteristics of Polysaccharides

2.3.1. The Compositions of Monosaccharide. At first, 20.0 mg of polysaccharides was dissolved in 2 mL of 2 mol/L trifluoroacetic acid. The reaction solution was sealed and fully hydrolyzed at 100°C for 8 h. The reaction vessel was removed out and cooled down to room temperature. After centrifugation at 1000 rpm for 5 min, the supernatant was neutralized with NaOH to pH 7.0 and freeze-dried as the hydrolyzates of polysaccharides.

The monosaccharide derivatives were prepared before HPLC analysis. 80 μL of each standard monosaccharide solution (0.2 mol/L) was accurately measured and mixed in one tube, followed by adding 100 μL of 0.3 mol/L NaOH and 1.2 mL of 0.5 mol/L 1-phenyl-3-methyl-5-pyrazolone which

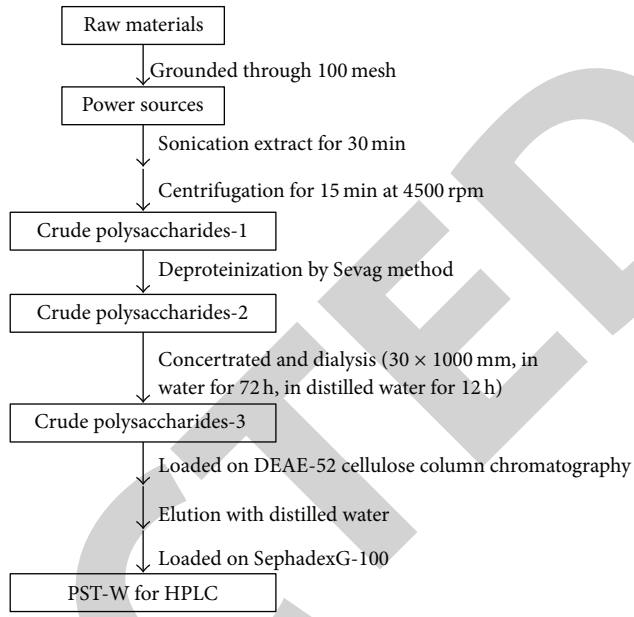

Figure 1: The extraction and purification process in detail.

dissolved in methanol. The mixture was denatured at 70°C water bath for 40 min and then cooled down to room temperature and neutralized with HCl. Thereafter, it was extracted for three times with 1 mL $CHCl_3$; the upper aqueous phase contained the derived products of monosaccharide. The derivatives for hydrolyzates of polysaccharide (PST-W) were also done according to the method mentioned above [8, 9].

HPLC-UV detection was conducted in Agilent 1100 chromatographic system with Waters Symmetry C18 column (150×4.60 mm) at the detecting wavelength of 245 nm. The injection volume was 20 μL with flow rate of 1.0 mL/min at 40°C. The mobile phase was ammonium acetate buffer (CH_3COONH_4-CH_3COOH, modified to pH 6.0 with acetic acid)-acetonitrile (85 : 15, v/v).

2.3.2. PST-W Methylation Analysis. Two milligrams of PST-W was accurately weighed and vacuum dried at 70°C for 3 h. 2 mL of anhydrous dimethyl sulfoxide was added and stirred till it was dissolved. 1.8 mol/L of methylsulfinyl anion was added and followed with nitrogen stream. Abundant precipitations were shown but they disappeared and dissolved again after stirring. 1 mL of methyl iodide was added dropwise into the solution, which was kept in room temperature below 30°C and stirred until a clear pale yellow was shown. After reaction stopped 1 h later, the methylation products were filled in a dialysis bag to dialyze in the flowing water flow for 24 h. Then it was concentrated and freeze-dried for use. Its methylation level could be checked by IR spectrum. Methylation should be repeated if it is not complete.

Subsequently, the methylated polysaccharide was hydrolyzed and followed with acetylation. The 1 mL formic acid was added into certain amount of methylated polysaccharide, which was in an Abe tube full of nitrogen.

It was put in 100°C oven to hydrolyze for 6 h. After that, formic acid was moved and followed by 0.5 mL of 2 mol/L trifluoroacetic acid to hydrolyze methylated polysaccharide again in the same process. The products were resolved in 0.5 mL water and deoxidized by 2 mg sodium borohydride at 30°C for 4 h. The next step was acetylation which was realized by pyridine and acetic acid [10]. The acetylation products were dissolved in 1 mL of methanol. After the organic membrane filtration, the solution can be used for GC-MS analysis.

The GC column was Agilent 122-2932 DB225 (0.25 mm × 30 m × 0.25 μm) followed by MS detector MSD. Temperature program began with initial temperature of 110°C. The heating rate was 7°C/min. And temperature was kept at 230°C for 18 min. The temperature at injector was 230°C. Carrier gas was helium. Injection volume was 1 μ with 1.0 mL/min flow rate of carrier gas. According to the data of spectra in standard CCRC database, the connecting bond type of sugar would be confirmed.

2.3.3. NMR Analysis of PST-W. PST-W of 15 mg was dissolved in 0.5 mL D_2O, using TMS as an internal standard. ^{13}C-NMR and ^{1}H-NMR spectra were measured by the Bruker AM-400 MHz superconducting NMR instrument.

2.4. Antioxidative Activity In Vitro

2.4.1. Determination of Total Reducing Capacity. It was conducted by ferric reducing ability assay [11]. 3.0 mL of phosphate buffer (pH 6.8, 0.2 mol/L) and 2.5 mL of 1% potassium ferricyanide ($K_3Fe(CN)_6$) solution were added to the polysaccharide solutions with different concentration. After rapid mixing, 45°C water bath for 30 min, immediate cooling, and adding 3.0 mL of 10% trichloroacetic acid (TCA) solution, the solution was centrifuged at 6000 rpm for 20 min. 3.0 mL of the supernatant was mixed with 2.0 mL of distilled water and 1.0 mL of 0.1% ferric chloride ($FeCl_3$) solution and measured for its absorbance at 700 nm wavelength. The higher absorbance means the reducing power is stronger. In the comparison with distilled water as negative control and vitamin C (VC) solution as positive control, the experiment was repeated three times for each sample and the average value was calculated.

2.4.2. Determination of 1,1-Diphenyl-2-picrylhydrazyl Radical 2,2-Diphenyl-1-(2,4,6-trinitrophenyl)hydrazyl (DPPH) Radical Scavenging Activity. According to [12], the reaction system included 1.0 mL of polysaccharide solution with different concentrations, 2.0 mL of 0.2 mmol/L DPPH-ethanol solution and 2 mL of 95% ethanol. All were mixed well and reacted in the dark for 30 min. The absorbance was measured at a wavelength of 517 nm. 2.0 mL of 95% ethanol solution was used instead of DPPH as blank sample. The solution in control group was 2.0 mL of DPPH solution mixed with 3.0 mL of 95% ethanol. Vitamin E (VE) was applied as positive control. The lower absorbance of the reaction system indicates the stronger DPPH radical scavenging activity. The rate of DPPH radical scavenging is calculated according to the following formula: $I/\% = ((A_0 - A_1) * 100)/A_0$.

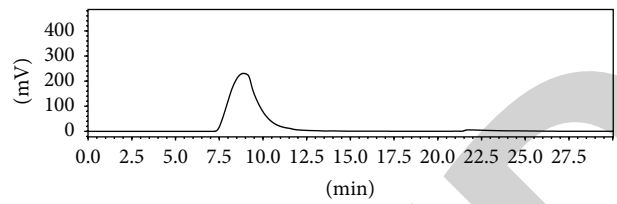

Figure 2: Purity identification of truffle polysaccharide (PST-W) by HPLC-UV.

$I/\%$ represents the percentage of clearance rate; A_1 is the absorbance of sample group; A_0 means the absorbance of control group. All samples were tested in triplicate, and the average value was calculated.

2.4.3. Determination of $O_2^{-\bullet}$ Clearing Ability. Using pyrogallol autoxidation method [13], pyrogallol in alkaline conditions can cause autoxidation. To each tube containing 6.0 mL of Tris-HCl buffer (50 mmol/L, pH = 8.1), 0.5 mL of polysaccharide solution with different concentrations was added. The mixture is in the water bath of 37°C for 10 min. Then 1.0 mL of the hydrochloric acid solution of pyrogallol (7 mmol/L) was added, shaken, and reacted precisely for 4 min. After that, the reaction was quenched with 0.5 mL of concentrated HCl. The absorbance was measured at a wavelength of 325 nm. The distilled water was used as blank sample, and VC was used as positive control. $O_2^{-\bullet}$ clearing ability was estimated based on the following formula: $I/\% = ((A_0 - A) * 100)/A_0$. $I/\%$ represents the percentage of clearance rate; A_0 is the absorbance of control group; A indicates the absorbance of sample solution. All samples were tested in triplicate, and the average value was calculated.

2.5. Statistical Analysis. t-test was used to make comparisons between the mean values of independent samples. The analysis was performed by applying the SPSS statistics system (version 16.5). Significance was defined as $p < 0.05$ and the variables are presented as the mean ± SD.

3. Results

3.1. The Yield of Polysaccharides (Dry Weight). The yields of crude polysaccharides-1, crude polysaccharides-2, and crude polysaccharides-3, measured by phenol-sulfuric acid method, were 3.48%, 2.13%, and 1.79%, respectively. The yield of pure PST-W was 0.41%. In this process (Figure 1), three crude polysaccharides were obtained and comparing their antioxidization abilities with PST-W was attempted.

The carbohydrate polymer (PST-W) might be isolated as neutral polysaccharides. After the purification of SephadexG-100 column chromatography, the main peaks were collected, concentrated, and finally analyzed by HPLC-UV (Figure 2). In our previous study about molecular weight of polysaccharides [7], several dextran standards with different molecular weights got different retention time (RT) in the same HPLC conditions. So, according to the relationship between RT and molecular weight, the formula can be obtained as Ig(M) =

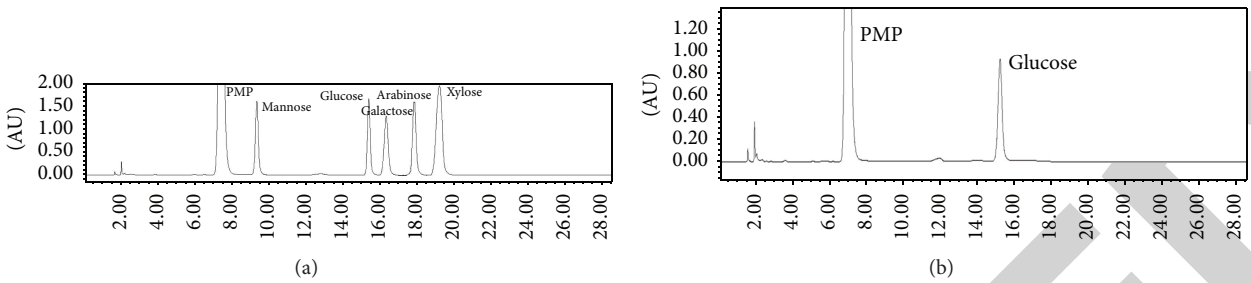

Figure 3: HPLC spectrum of acetylated aldononitrile derivatives of (a) mixed standard monosaccharide and (b) PST-W.

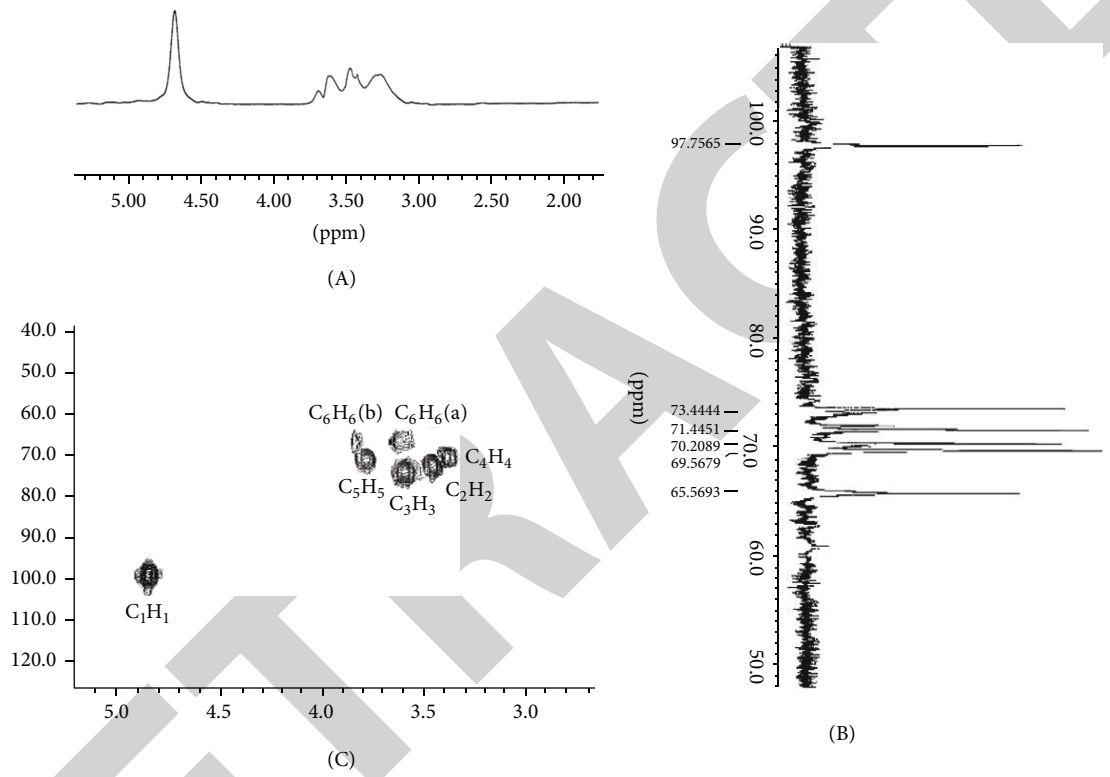

Figure 4: The (A) ^{1}H-NMR, (B) ^{13}C-NMR, and (C) HMQC spectra (D_2O, 500 MHz) of PST-W.

$-0.0817RT + 6.587$. The molecular weight of PST-W was calculated as 7.29×10^5 Da separately.

3.2. Structural Characteristics of Polysaccharides

3.2.1. Monosaccharide Compositions. By the quantitative method with external standard, PST-W was glucan only containing D-glucoses (Figure 3).

3.2.2. The Methylation Analysis of PST-W. The sample of PST-W was fully methylated, followed by complete acid hydrolysis, and finally made into acetylated derivatives for GC-MS analysis, and the results were shown in Table 1. Referencing the literature from Guo et al. [10], the only derivative of 1, 5, 6-tri-O-acetyl-2, 3, 4-tri-O-methyl-D-glucitol could be detected obviously in PST-W. It could be inferred that PST-W was mainly composed of (1 → 6)-linked glucose group.

3.2.3. The NMR Analysis of PST-W. As shown in Figure 4, NMR analysis was carried out to further verify the molecular structure of PST-W [10]. There were six peaks with basically equal height in PST-W ^{13}C-NMR spectrum. From low field to high field they were 97.74, 73.42, 71.43, 70.21, 69.57, and 65.59. The chemical shift of 97.74 was the signal peak of C1 on the terminus [14]. It was approved again that PST-W was composed of α-D-glucose and it was identical to the results of infrared spectra. There was signal peak of C6 substitution at 65.59, with no other signal peaks at 80.00. So it could be concluded that there was no C2, C3, or C4 substitution existing. This result was consistent with the methylation [15]. The experimental results of ^{1}H-NMR and ^{13}C-NMR showed that PST-W might be a linear glucan connected by α-D-(1 → 6), and its structure could be determined as follows: [→6) α-D-Glcp (1 → 6) α-D-Glcp (1→]$_n$.

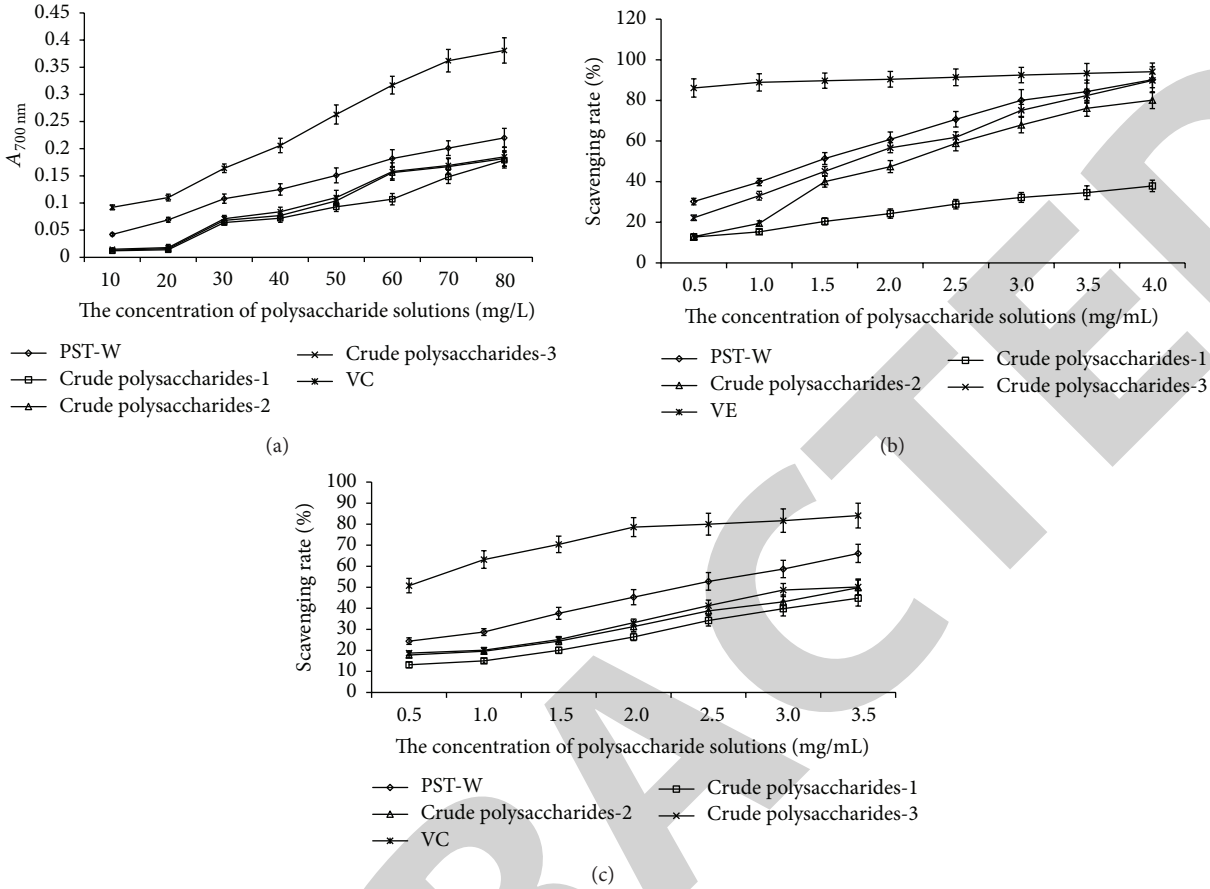

Figure 5: Antioxidant activities of PST-W and crude polysaccharides on potassium ferricyanide ((a): total reducing power), DPPH radical (b), and superoxide anion radical (c) with vitamin C or vitamin E (VC/VE) as a positive control. Data are mean ± SD values ($n = 3$).

Table 1: The GC-MS results of methylated PST-W.

Methylated sugar residue	Retention time (min)	Major ion peak of MS (m/z)		Glycosidic bond chaining
		PST-W	References [10]	
2,3,4-Me_3-Glc	25.239	101, 117, 129, 161, 189, 233	101, 117, 129, 161, 189, 233	→6) Glc (1→

3.3. In Vitro Antioxidant Activity

3.3.1. Determination of Total Reducing Capacity. Considering that the reducing ability is obviously positive related to antioxidant activity, the absorbance of reactive products at 700 nm indicates the intensity of reducing ability. The results of each sample were shown in Figure 5(a). It seemed that, along with the purification procedure of crude polysaccharide, the crude extract with higher purity inferred to stronger reducing power. So, the antioxidant effects of polysaccharide extracts could be listed as VC > PST-W > crude polysaccharides-3 > crude polysaccharides-2 > crude polysaccharides-1. The activities of three crude polysaccharides were similar and weak.

3.3.2. Determination of DPPH Radicals Scavenging Activity. DPPH radicals are a kind of stable aromatic radicals. The scavenging activity of antioxidants on DPPH is generally acknowledged as the total ability on clearing radicals [16]. All samples showed their abilities on scavenging DPPH radicals (Figure 5(b)). When the concentration of polysaccharides samples was 4.0 mg/mL, the clearance rates of PST-W, crude polysaccharides-2, and crude polysaccharides-3 were 90.2%, 80.1%, and 89.8%, close to the 94.1% of VE. The clearance ability of crude polysaccharides-1 at 4.0 mg/mL also achieved 37.9%.

3.3.3. Determination of $O_2^{-\bullet}$ Clearing Ability. $O_2^{-\bullet}$ is the first one of all oxygen radicals and can product other oxygen radicals through series of reactions. It is highly toxic, and the clearing capacity for extra $O_2^{-\bullet}$ is particularly significant [17]. Compared with VC, the clearing ability of all crude polysaccharides samples was relatively weak (Figure 5(c)). It is surmised that polysaccharide might only react with $O_2^{-\bullet}$ by its hydrogen on reactive hydroxyl, which could not inhibit the product of $O_2^{-\bullet}$ fundamentally.

Table 2: IC_{50} values of PST-W and crude polysaccharides for scavenging DPPH and superoxide anion radical (mg/mL).

Samples	DPPH radical	$O_2^{-\bullet}$
PST-W	2.81 ± 0.008	4.73 ± 0.017
Crude polysaccharides-1	6.48 ± 0.041	7.55 ± 0.036
Crude polysaccharides-2	4.17 ± 0.020	7.01 ± 0.027
Crude polysaccharides-3	3.44 ± 0.012	6.56 ± 0.015
VE	0.15 ± 0.003	—
VC	—	0.87 ± 0.002

Means ± SD ($n = 3$) followed by $*$, $**$, $***$ are significantly different from values obtained for crude polysaccharides-1 ($^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; t-test).

3.3.4. Value of IC_{50}. Each assay on antioxidant activity was reproductive and repeatable. According to Table 2, the antioxidant capacities of PST-W and crude polysaccharides on scavenging DPPH and superoxide anion radical were calculated in the form of IC_{50}. The values of IC_{50} indicated that all of PST-W, crude polysaccharides-2, and crude polysaccharides-3 were relatively good scavenger for DPPH radicals with IC_{50} of 2.81, 4.17, and 3.44 mg/mL, respectively. However, $O_2^{-\bullet}$ clearing abilities of PST-W and crude polysaccharides were obviously weaker than their capacities on DPPH.

4. Discussion and Conclusion

In recent research [18], 5 mg/mL polysaccharide extracts of *Perigord Truffle* (PEPT) demonstrated its high scavenging abilities on hydroxyl radicals and DPPH with EC_{50} of 0.73 mg/mL and 1.12 mg/mL, respectively. In the study against redox reaction induced by potassium ferricyanide, ferric chloride, and trichloroacetic acid, EC_{50} of PEPT was 2.46 mg/mL. In another study, PEPT was divided into three groups according to molecular size by dialysis membrane: TIP-III group included the ingredients of PEPT with molecular weight >100 Da; TIP-II group contained components of PEPT with molecular weight between 50 and 100 Da; TIP-I group were compositions of PEPT with molecular weight of <50 Da [19]. The TIP group with smaller molecular weight resulted in higher clearance and stronger antioxidant activities on DPPH radicals, $^{\bullet}OH$, $O_2^{-\bullet}$, and iron ions (TIP-III > TIP-II > TIP-I).

To the best of our knowledge, this was the first investigation on the chemical characteristics, monosaccharide composition, and antioxidant activities of polysaccharide PST-W from *Perigord Truffle* (*Tuber huidongense*). PST-W is the main soluble polysaccharide of truffle. In this study, our results indicated the presumed molecular structure of PST-W was $[\rightarrow 6)\ \alpha\text{-D-Glcp}\ (1 \rightarrow 6)\ \alpha\text{-D-Glcp}\ (1\rightarrow]_n$, wherein the value of n could be calculated to be about 2×10^3. In the determination of total reducing capacity, the reducing abilities of polysaccharide extracts could be listed as VC > PST-W > crude polysaccharides-3 > crude polysaccharides-2 > crude polysaccharides-1. All of PST-W, crude polysaccharides-2, and crude polysaccharides-3 were relatively good scavenger for DPPH radicals. However, $O_2^{-\bullet}$ clearing abilities of PST-W and crude polysaccharides were obviously weaker. For the antioxidant activities of PST-W and polysaccharide extracts, the activities of total crude extract were the worst, indicating that the impurities might negatively affect the antioxidant activity. Thus, the separation and purification of polysaccharides were significant to increase the antioxidant activity in some degree.

It was proposed that the possible antioxidant mechanism of PST-W may involve hydrogen donation to break chain reactions and free radical scavenging ability resulting from the abstraction of anomeric hydrogen from the internal monosaccharide units of polysaccharides [20]. Most importantly, the biological activities of polysaccharides are associated tightly with molecular weight, uronic acid, monosaccharide composition, degree of substitution and branching, structure, and conformation. In particular, the antioxidant activities of different polysaccharide fractions recently were correlated positively with the increasing sulfate group content [21, 22] and the decreasing molecular weight of polysaccharides [23]. Considering that there is no sulfate group in the branch of PST-W, it may answer for its relative week antioxidant activity.

It was also demonstrated that the Chinese truffle (*Tuber huidongense*) is a healthcare food and a source of natural antioxidants, and further investigation of its antioxidant properties in vivo and other studies of the biological activities of these polysaccharides are in progress. Further studies on their application in the food, medical, and cosmetic industries are worth exploration.

Ethical Approval

This study received the approval of local Animal Ethics Committee (no. 2010021137).

Competing Interests

The authors declare that there are no competing interests regarding the publication of this paper.

Acknowledgments

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